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THE FORMER LAND CONNECTION BETWEEN AFRICA AND SOUTH AMERICA

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There are two lines of inquiry which lead to a common conclusion, namely, that in former ages there was a notable land area where now the waters of the Atlantic lie. The first is concerned with the evidence afforded by islands in mid-ocean, and the second makes use of the character and conditions of deposition of the rocks on the continents bordering the ocean, and the distribution of animals now living on either side.

The bulk of the evidence is naturally accumulated in the second line of inquiry, because the continents are more accessible to observation and investigation; but even a little testimony from oceanic islands is of very great value, for these are formed by the piling-up of lavas, and the vents penetrate the ocean floor and bring up fragments of the solid crust beneath, so that we can actually handle and examine the constituent rocks of the submerged land.

In setting out the arguments on the first line of inquiry, it is necessary to define what is meant by a continental type of rock. Sir John Murray's list of continental types is gneiss, schist, sandstone, and compact limestone; and generally the term seems to be applied to any rock formed from the detritus of a land-mass, bearing in mind that it is generally accepted that sediments are deposited within two hundred miles of the coast. The inclusion of schists and gneisses seems to imply, in addition, that rocks may be included in the list of continental types which have been subjected to deformation, the underlying idea being that earth-movements, such as those which produce mountain-folds, are confined to the regions of the globe that have been, or are, above the level of the ocean. The average specific gravity of continental types of rock is taken to be 2.68. We owe this term to the theory of Dana, Wallace, and others, that the oceans and continents have remained pretty much in the same places during geological time. The opposite of continental rock is, obviously, an oceanic rock, though this term is never actually used, the meaning being conveyed by various phrases, such as "the rocks forming the ocean floor," or "the sub-oceanic crust." Now, since the continents as a whole are less elevated above mean sea-level than the ocean floors are depressed below it, and since the density of water is less than half that of rock, it is obvious that if the densities of the continents and ocean floors were the same, the water would be attracted by the land-masses and heaped up along the shores. Such is actually assumed to be the case by Suess in the introduction to his *Antlitz der Erde,* but Fisher adduces very strong arguments in favor of the view that, setting aside rotational effects, the sea-level is sensibly spherical. In the latter case, the rocks of the sub-oceanic crust must be denser than the continental types to keep the water in place, and it is assumed that they are composed of basic original magma, and of basaltic flows from submarine volcanoes, which were more dense than the material of the continental crust.[1] The specific gravity of the rocks composing the ocean floor is taken to be 2.96. Thus it appears that in respect to the density of the sub-oceanic floor and the consequent form of its hydrosphere we have two rival schools, the one maintaining that the ocean surface forms a series of troughs between the continents, the other that the hydrosphere is sensibly spherical. This point must be settled before we can arrive at any comprehensive and satisfactory explanation of the geology of the earth as a whole; and, as far as I know, the materials at present available are not sufficient to enable one to give an irrefutable answer one way or the other. Even if Stokes, Pratt, and Faye, quoted by Fisher, go too far in one direction, and Fischer, Hann, and Listing, quoted by Suess, go too far in the other, yet the work of v. Drygalski[1] shows that there are factors which render both to a certain extent reconcilable. A great advance will have been made if it can be sufficiently proved that there was once a land surface where now the Atlantic Ocean or some notable part of it, lies; and I will now present the arguments n favor of this view.

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[1] Fisher, *Physics of the Earth's Crust,* chap. 25, and Appendix, p. 16.

Evidence from Ascension Island.—Ascension Island, like the Tristan group and St. Paul's rocks, lies in the mid-Atlantic ridge. Composed chiefly of volcanic rocks, there are abundant traces of the substructure being granitic in nature. Darwin states that in the neighborhood of the Green Mountain fragments of extraneous rocks are frequently met with imbedded in the midst of scoriæ.[2] Professor Renard confirms this, and mentions as occurring in this manner, granite, granitite, diabase, and gabbro, "torn up from the depths by eruptions."[3] There is no record of the granite basis appearing above the water-line; but if one takes these observations and considers them in the light that Woolnough has thrown on the Fiji Islands, another group which until recently had been thought to be purely volcanic, the true significance of these ejected blocks is made clear. In Fiji, Woolnough found that the whole group was underlain by a basis consisting of granite, quartz-diorite, quartzite, slates, and old sedimentary rocks of an indeterminate age,[4] and I confidently look to the results of his second expedition for affording still more striking evidence for the continental origin of these islands.

Evidence from St. Paul's rocks.—A great deal has been written on the ultra-basic rocks from this small mass of land in mid-ocean, and the opinions as to whether they are igneous or metamorphic have been equally balanced. The deformation of crystals imbedded in the matrix is such, however, that we must assume that the rock has been subjected to earth-movements, and in spite of the islands lying in a region of active submarine volcanic action, such a careful author as Neumayr was satisfied that this ultra-basic rock—serpentine, peridotite, or sherzotite, whatever we choose to call it—was a metamorphic and not an eruptive rock.[1]

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[1] *Zeitschrift der Gesellschaft für Erdkunde* (Berlin, 1887).

[2] *Geological Observations on Volcanic Islands*, 1851, p. 40.

[3] Challenger Reports, *Physics and Chemistry*, Vol. II, Part 7, p. 62.

[4] *Proceedings of the Linnean Society of New South Wales*, 1903, Part 3.

Evidence from Tristan d'Acunha.—In the Tristan d'Acunha group one block of gneiss was obtained by Mr. Hammond Tooke on a voyage thither in H. M. S. "Odin." Further specimens from Nightingale Island showed fragments of an earlier consolidated rock imbedded in a glassy matrix; the fragments were very minute and had the appearance of having been derived from a felsite or microgranite.[2] Both these cases would have been too small evidence on which to build any theory of the rock substructure of the islands, did not the description of Ascension Island support them. In Carmichael's account of the ascent of the peak on Tristan d'Acunha we read that the plain from which the central cone rises "is encumbered with large detached masses of porphyritic stone, and with others, inclosing crystals of sulphur or augite, which seem to have been ejected in their present state from the interior of the mountain."[3] Latter-day petrologists may smile at a man who cannot distinguish between crystals of sulphur and augite, but Carmichael was sound on general geological questions, and his description of Cape Town, with the sandstone resting on slate and granite with dolerite dykes,[4] is far better than many of the later accounts.

Volcanic ejectamenta as indices of deep-seated formations.—It is a remarkable fact that we can thus sample the deep-seated rocks, far below the zone of direct observation, by the ejectamenta of volcanoes. In South Africa I have made use of them in the Drakensberg, where many thousands of feet of Permian, Triassic, and perhaps Jurassic strata lie upon an Archæan base,[5] and in the central Karroo portions of the Palæozoic floor are brought to the surface in this manner. Often enough, in South Africa especially, the fragments torn from the throats of volcanic pipes have been rounded by attrition, and assume the characteristics of water-worn bowlders. In crush-breccias at Kuysna I have found rounded bowlders of exactly the same shape formed on the very spot from which they have been broken. The accounts of crush-breccias from the Isle of Man and Canada bear out the same view, namely, that rock-fragments can be rounded by simple dry friction. This point is important as the presence of apparently water-worn bowlders in volcanic agglomerates, such as those of the Kimberly diamond pipes, has frequently been adduced as evidence of water-action.

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[1] *Erdgeschichte* (Leipzig, 1890), p. 199.

[2] *Transactions of the South African Philosophical Society*, Vol. XVI (Cape Town, 1905), p. 49.

[3] *Transactions of the Linnean Society*, Vol. XII (London, 1817), p. 491.

[4] Biographical sketch, *Hooker's Botanical Miscellanies.* Vol. II (London, 1831), pp. 1–59, 259–89.

[5] "The Volcanoes of Matatiele," *Annual Report of the Geological Commission* (Cape Town, 1902), p. 39.

The comparative coolness of these volcanic eruptions is remarkable, and is such that in some cases, where fossiliferous strata contribute to the fragments in the volcanic pipe, the structure of the remains are as fresh as in the parent rock. In Scotland Sir A. Geikie records a vent at Elie Neck in which there are fragments of crinoidal limestone which show no trace of metamorphism, and their crowded organisms are as clearly recognizable as in pieces of limestone from a quarry.[1] In Kimberly the fragments of shale in the blue mass are quite fresh, and blocks containing fossil fish are as unaltered as if they had been procured from their original resting-place.

The temperature, however, was greater in other cases; for instance, Branco records blocks of middle Lias marly clay from the agglomerate in the Schleursbach volcano in Swabia, which have been baked and the included belemnites turned to white marble.[2] In the far south, Phillipi[3] describes blocks of granite entangled in lava on the top of the Saussberg; the ferro-magnesian minerals are melted, and the lava occupies the space they once filled by a sort of pseudomorphism, while the quartz and felspar remain intact. These blocks may have been derived from the surface of the ice-cap which once extended over the Saussberg, but the prolonged heating of the blocks, sufficient to melt the hornblende, seems rather to indicate that the blocks came up in the lava from below.

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[1] "Geology of Eastern Fife," *Memoirs of the Geological Survey of Scotland* (Glasgow, 1902), p. 241.

[2] *Swabiens 125 Vulcan-Embryonen* (Stuttgart, 1894), p. 546.

[3] *Veröffentlichungen des Instituts für Meereskunde*, Heft 5, 1903, p. 126.

I cannot forbear in this connection from drawing attention to a similar result which was obtained in the earliest experimental work which was carried out on the melting-points of rocks. Sir J. Hall, in heating some blocks of basalt from Arthur's Seat, near Edinburgh, found that at 100° of Wedgwood's pyrometer the whole was changed to a pure black glass, but at 60° the felspar remained unchanged while the hornblende disappeared, and formed a glass along with the basis of the stone.[1]

The further action of heat in volcanoes is shown in the Nightingale rocks, where fragments have been included in the liquid magma and in part remelted. And a still further stage, possibly, is exhibited in the rocks of Tristan d'Acunha, where sphene occurs in great abundance.[2] This mineral, together with perovskite, occurs in certain eruptive rocks, which, as far as I have observed them personally, suggest that sedimentary rocks have been absorbed in the molten magma. Perovskite is an accessory mineral in the melilite basalts of the Karroo volcanic pipes, and also in the mass of melilite basalt which occurs in the faulted Cretaceous rocks of the south coast of the Cape Colony;[3] it can be regarded, in fact, as an alteration product of the ilmenite in the original magma, from being brought into contact with limestone in the zone of intense pressure. The extraordinary abundance of sphene in the Tristan d'Acunha rocks I am inclined to view as the result of the interaction of a rock magma containing titanium acid and a limestone.

The final stage of the temperature gradient is that in which the rock is entirely molten, and the molecules of the various elements left to sort themselves into groups to form minerals without any influence from the inclusion of extraneous solid materials. If we could know the whole history of igneous rocks, perhaps these too might tell us something about the substructure of the earth beneath the volcanic vents, for it is not an entirely untenable theory that they are derived from the fusion of pre-existing rocks, sedimentary and otherwise, which have been subjected to dynamical stress.

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[1] "Experiments on Whinstone and Lava," *Transactions of the Royal Society* (Edinburgh, 1798).

[2] *Transactions of the South African Philosophical Society*, Vol. XVI, p. 46.

[3] *Annual Report of the Geological Commission*, 1898, p. 62; *ibid.*, 1903, pp. 43–67.

I have spoken hitherto mostly of the large fragments torn off from the throat of the volcano, but the inclusions in the Nightingale rock are more of the nature of fine dust. Such volcanic dust aggregated into beds would be known as a tuff, but it has not been generally recognized till recently that such tuffs may be built up entirely of non-volcanic materials. In the peperino of Italy we have a leucite tuff with many inclusions of non-volcanic rocks, such as limestone, sometimes in large blocks, at others in the form of fine dust. In the cave sandstone of the Drakensberg we have a tuff which is composed entirely of non-volcanic dust, grains of quartz, microcline, plagioclase, tourmaline, epidote, etc., with only an occasional ash-bed. I suspected its origin, when first studying it in Matatiele, from the fact that it was found thickest near the volcanic vents. Its nature, also, showed clearly that it was not an ordinary sediment; for there are beds of this rock 800 feet thick without a trace of stratification. Sometimes there is stratification; either a plane passes slantingly through the mass from top to bottom, or it is curved and twisted as if the whole material had been stirred about in a gigantic pot. The structure of the rock was such that I finally decided that it must have been ejected as a liquid mud exactly like the Italian peperino, and that the constituent grains had been blown from the substratum of granite and Archæan schists by explosions. Von Knebel has described similar tuffs composed of disrupted granite from the Ries in Germany.[1]

In 1845 Ehrenberg described a remarkable tuff from the Island of Ascension containing infusoria, which he called a pyrobiolith.[2] Prestwich surmised that these "diatoms" had lived in subterranean caverns which the explosion had traversed,[3] but the *Challenger Reports* state that the organic remains are the siliceous particles of grasses. It seems probable that this tuff was erupted as a boiling liquid mud, which, traversing a plain covered with grass, tore off by rolling action and incorporated grass fragments in the substance of the mud. In view of the presence of granite blocks in the lavas, it is quite possible that some of the tuffs on these volcanic islands will turn out to be of the same nature as the granitic tuffs such as are found in the Drakensberg and the Ries in Germany.

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[1] *Zeitschrift der Deutschen Geologischen Gesellschaft*, Vol. LV (1903), pp. 236–95.

[2] *Berichte der Königlichen Akademie der Wissenschaften* (Berlin, 1845), p. 140.

[3] *Proceedings of the Royal Society*, 1886, No. 246, p. 156.

In the Atlantic islands that do not stand on the central ridge continental types of rocks are also found, as, for instance, in the Canary Islands, where gneiss occurs; in the island of Mayo, in the Cape Verde group, Doelter found compact limestones and crystalline schists—traces, he maintains, of an ancient continent.[1]

On the whole, therefore, the evidence of a land connection between Africa and South America, afforded by the islands in mid-ocean, is suggestive, but far too little investigated to be worth much at the present time. The oceanic islands are not favorably situated for lengthened research; yet a very serious lacuna will exist in our knowledge of the geology of the earth as a whole, if they are not systematically studied. The surprising results of Woolnough in the Pacific makes one expect similar results from the Atlantic islands; and then there are the islands in the Indian Ocean, about which we know very little indeed, and the Aleutian Islands in the north Pacific, which are similarly unexplored. I urge, therefore, that these oceanic islands can and do afford evidence of the sub-oceanic crust, and if we are to understand the relation of our present continents to the waters that encompass them, we must not rely solely on the facts as presented to us in the most convenient places, round our homes, but we must put off from our shores and seek knowledge in isolated rock-masses of the ocean.

In the second line of inquiry we can consider the evidence from the American or the African side where the land bridge is supposed to have emerged.

In South Africa in Silurian times we have a remarkable band of sandstone 5,000 feet thick, coarsely false-bedded throughout, stretching from the west coast at a point about midway between the mouth of the Orange River and Cape Town, to Port Elizabeth, and then coming in again at St. John's River, quite similar in constitution, and passing eastward to Natal. This was succeeded by deeper water deposits containing characteristic American forms of life, such as *Leptocœlia flabellites*, *Vitulina pustulosa*, *Spirifer orbignyi*, *Ambocœlia umbonata*, *Grammysia chemungensis*, *Bellerophon reissi*, and many others. Following these Bokkeveld Beds come the sandstones of the Witteberg Series (the Cauda-galli grits of North America). And after this the Dwyka conglomerate, a glacial bowlder-clay with a peculiar assortment of inclusions, all of which have been now traced to rocks *in situ* in the north of the Colony and Transvaal. The whole series is plainly indicative of the existence of a land-mass in Palæozoic times whose shores ran through the south of the Transvaal and the north of the Cape Colony. The conglomerates in the Table Mountain sandstone in the west show that the land was near at hand there. But after Silurian times there is no evidence in South Africa that the sediments were derived from the west; they seem all to have been derived, as far as the Cape Colony is concerned, from the north.

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[1] *Verhandlungen der K.-K. Geologischen Reichsanstalt* (Wien, 1881), p. 16.

Quite otherwise is it in South America. Katzer finds there the most complete evidence for the existence of a land-mass on the east, whence the sediments that now go to form the mainland were derived,[1] and this continent existed up to Tertiary times. The long residence of this author at Para and his wide acquaintance with the literature of South America make his conclusions peculiarly valuable. In Devonian times the existence of the *Leptocœlia flabellites* fauna in South Africa, the Falkland Islands, South and North America, has led many to suppose that the European seas were separated from the waters under which the Devonian sediments were being laid down containing this fauna, by a land bridge; Katzer has called it the Atlantico-Ethiopic Continent,[2] and I, Flabellite Land, after the characteristic fossil *Leptocœlia flabellites*. From a review of the Jurassic faunas Neumayr came to the same conclusion as others have come to, from considering the extension of the Devonian faunas.[3]

Finally, if the bridge lasted as late as the Tertiary period, we must expect the distribution of land animals to have been affected by it, and such we find to be actually the case. The late Dr. Blanford, in his anniversary address to the Geological Society of London in 1890, went thoroughly into the question in regard to the fresh-water fishes and batrachians. In a subsequent letter I received from him he wrote:

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[1] *Grundzüge der Geologie des unteren Amazonasgebietes* (Leipzig, 1903), p. 239.

[2] *Bol. d. Mus. Paraense*, Vol. II (1895), plate, p. 237.

[3] *Denkschriften der K.-K. Akademie der Wissenschaften*, Wien, Vol. II (1885), p. 132.

> I have long been aware of the extraordinary connection between the faunas of Africa and South America, only a very few examples of which were known when I wrote about ancient continental connections in 1890. For instance, the fresh-water crustaceans have been examined by Dr. Ortman,[1] spiders by Pocock,[2] and several other groups by Dr. Scharff.[3] I have heard of an amphisbæna (belonging to the family of lizards, chiefly confined to Africa and South America) turning up at one of the South Atlantic islands (Trinidad, off the Brazilian coast I think), but I cannot now find the reference.

Boulenger, in his presidential address to the zoölogical section of the British Association at the South African meeting, stated that, although it was possible to get the present distribution of fresh-water fishes without a land-bridge between Africa and South America, yet a connection would immensely simplify the explanation of their dispersal.

There are many naturalists who do not think that the evidence from living forms of life is sufficient to bring into existence in past ages such a tremendous rearrangement of the land-surfaces, but if the geologists from their side can adduce satisfactory reasons for such a submerged land connection, most of their opposition would vanish, for the connection does help to explain matters very considerably. If geologists rely on elaborate arguments to prove their contention, zoölogists are not likely to take the trouble to examine them; and this brings me back to my former statement, that even a little evidence from oceanic islands is of very great weight. A block of slate containing *Leptocœlia flabellites*, found in Tristan d'Acunha or similar Atlantic islands, would prove more by itself than any attempt to reconstruct the direction of sedimentation in past ages, no matter how sound the arguments were. I have shown that such a find is by no means impossible, and I have endeavored to make clear what important issues hang on the proper investigation of oceanic islands.

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[1] *Proceedings of the American Philosophical Society*, Vol. XLI (1902), pp. 267–400.

[2] *Proceedings of the Geological Society*, 1903, Part I, p. 340.

[3] *Proceedings of the Royal Irish Academy*, Vol. XXIV.